Aerosol Science and Technology, 41:497–509, 2007

ISSN: 0278-6826 print / 1521-7388 online
DOI: 10.1080/02786820701225838

Analysis of Aerosolized Particulates of Feedyards Located in the Southern High Plains of Texas

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The objective of this study was to quantify, size, and examine the composition of particulates found in ambient aerosolized dust of four large feedyards in the Southern High Plains. Ambient air samples (concentration of dust) were collected upwind (background) and downwind of the feedyards. Aerosolized particulate samples were collected using high volume sequential reference ambient air samplers, PM_{10} and $PM_{2.5}$, laser strategic aerosol monitors, cyclone air samplers, and biological cascade impactors. Weather parameters were monitored at each feedyard. The overall (main effects and estimable interactions) statistical ($P < 0.0001$) general linear model statement (GLM) for PM_{10} data showed more concentration of dust ($\mu g/m^3$ of air) downwind than upwind and more concentration of dust in the summer than in the winter. $PM_{2.5}$ concentrations of dust were comparable for 3 of 4 feedyards upwind and downwind, and $PM_{2.5}$concentrations of dust were lower in the winter than in the summer. GLM ($P < 0.0001$) data for cascade impactor (all aerobic bacteria, *Enterococcus spp*, and fungi) mean respirable and non-respirable colony forming units (CFU) were 676 ± 74 CFU/m^3, and 880 ± 119 CFU/m^3, respectively. The PM_{10} geometric mean size ($\pm$GSD) of particles were analyzed in aerosols of the feedyards (range 1.782 ± 1.7 μm to $2.02 \pm 1.74 \mu m$) and $PM_{2.5}$ geometric mean size particles were determined (range 0.66 ± 1.76 μm to 0.71 ± 1.71 μm). Three of 4 feedyards were non-compliant for the Environmental Protection Agency (EPA) concentration standard (150 $\mu g/m^3/24$ h) for PM_{10} particles. This may be significant because excess dust may have a negative impact on respiratory disease.

INTRODUCTION

Air quality is an important public issue for urban (Seinfeld 2004) and rural populations (Schenker 1998). In recent years, a greater focus has been placed on agriculture industries, which cause air and water pollution (Horrigan et al. 2002; Centner 2001), and especially on concentrated animal feeding operations (CAFOs) (Centner 2003; Cole et al. 2000; Donham et al. 2002). Poultry, swine, dairy, and cattle CAFOs are becoming massive industries, many of which are owned by vertically integrated producer corporations (Mallin and Cahoon 2003). This industrialization of CAFOs brings with it opportunities, challenges, and responsibilities. Opportunities exist for better economics and a higher profit margin. The challenges are to increase efficiency and reduce the environmental impact, and the responsibilities are to produce a superior product, provide a wholesome work environment for employees and animals, and to provide a pleasing industrial plant site which does not pollute the environment (air, water, or land).

Aerosols of dust and odors are inherent with CAFOs. In the past, organic dust was considered a nuisance downwind (Sweeten et al. 1988); however, it may represent a potential health hazard to calves (MacVean et al. 1986) and humans (Seifert et al. 2003; Omland 2002). More attention is being paid to the size, composition, and quantity of these aerosol particles by federal and state regulators (Musick 1999). Specific regulations are in place for particles that are 10 μm in diameter (Cleland 1998) and specific regulations are being proposed for 2.5 μm diameter size particles (Musick 1999; Lloyd 2002). The smaller dust particles, 2.5 μm, can be inhaled deep into the alveoli of the lung. Recent epidemiological studies indicate that smaller ambient dust particles collected in urban centers occasionally appear to be associated with human mortality statistics (Dominici et al. 2000; Samet et al. 2000). Therefore, the size, concentration, and chemical composition of aerosolized particles generated by feedyards and other agricultural industries needs to be characterized and reported. A review (Omland 2002) established that farmers living in temperate zones can inhale substantial amounts of organic dust that might lead to respiratory disease and increased annual loss in lung function. In another review (Seifert et al. 2003), organic dust toxic syndrome (ODTS) was more likely to occur when higher concentrations and longer exposures to organic dust prevailed. Therefore, the analysis of feedyard dust has many interested parties (feedyard

Received 25 August 2006; accepted 10 January 2007.
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owners and managers, veterinarians and nutritionists, neighbors and the general public, and public health officials and regulators) who would like to review the scientific results obtained. There is a need to determine if feedyard dust poses a potential health hazard.

There are many sources for the generation of dust in feedyards (Purdy et al. 2004), including, feed mills, loading and unloading of feed trucks, vehicle exhaust, unpaved roads, cattle activity in dusty pens, semi-arid conditions, and winds. Thus far, frequent removal of manure (Stalcup 2005) and wetting of the pens and unpaved roads with water have been the best solutions (Simpson 1970; Andre 1985; Carroll et al. 1974) for decreasing the ambient dust. Bacterial, fungal, and endotoxin concentrations have been reported (Purdy et al. 2004; Wilson et al. 2002) for Southern High Plains feedyards. The objectives of this study are to quantify, size, and examine the composition of particulates found in ambient aerosolized dust of four large feedyards in the Southern High Plains of Texas during an eight day time period in the winter and summer.

MATERIALS AND METHODS

Sample Populations

Four commercial feedyards (FY1, FY2, FY3, and FY5) were used in the study. The feedyards were all within 100 km of each other. Their capacity ranged from 45,000 to 175,000 cattle/y (2000 Fed cattle survey, Southwestern Public Service Co., Amarillo, TX).

Experimental Design

Air particulate collecting equipment was placed upwind and downwind in the four feedyards. The average distance between the upwind and downwind air monitors was approximately 1.05 km. Air monitors in the upwind or downwind position were placed 6 m apart. The position of the air monitors were placed 6 m from the upwind and downwind boundary fences which contained the cattle.

Air Monitoring Instruments

Feedyard aerosolized particulates were analyzed by use of high volume (1 m^3/h) sequential Reference Ambient Air Samplers (RAAS-300 series). PM_{10} (Code of Fed. Reg. 1997, appendix K) (two) and PM $_{2.5}$ (Code of Fed Reg.,1997, appendix L) (two) monitors (300 RAAS series, Andersen Instruments, Smyrna, GA.)are stand alone sampling systems that meet the Federal Reference Method (FRM). Each filter (Whatman Filter Device 2 μm PTFE, 46.2 mm, Cole Palmer, Vernon Hills, IL) was identified and its weight (accurate to 10 μg) recorded after 33% relative humidity equilibration. This was done prior to the filters' use and again after the collection of ambient particulates. The $PM_{2.5}$ WINS impactor (provides a 2.5 micron cut point) glass fiber filter (Whatman 934-AH 37 mm, Cole Palmer, Vernon Hills, IL) was prepared with one drop of supplied oil which was replaced every 8 days, when the instrument was cleaned. The RAAS air flow rate was maintained at 16.5 L/min and the instrument was recalibrated (RAAS Operators's Manual, Section 8, 8-1-8-45, Andersen Instruments, Smyrna, GA) every 3 months.

Independent Laboratory Analysis

Feedyard dust, collected on $PM_{2.5}$ and PM_{10} filters, was analyzed for size, shape, and chemical composition. This provided an independent laboratory (Particle Technology Labs, Ltd., Grove, IL) control on the particle sizing capability of the $PM_{2.5}$ and PM_{10} monitors' performance under feedyard conditions. In addition, the analysis for chemical composition of specific dust particles could give information on the source of the dust. The particle sizing was performed on an Elzone, model 112 electrozone analyzer (Coulter technique) (Currently manufactured by Micromeritics Instrument Corporation, Norcross, GA). Electrozone analyzers are true particle counters and the data are reported in two formats, population count and mass concentration. The data are presented on a log basis as percentiles, median, mean, and mode. Then they are presented at specific equal distant points (0.77 sigma intervals) for plotting. Count (number) and or mass data are tabulated according to channel number (1-128), size in microns at the channel, counts in channel, and the cumulative percentage of counts greater than or equal to the indicated micron size. Frequencies of occurrence (count) data are converted to mass concentration data through the use of a classic formula Volume $= Nd^3$: where N is the number of particles at a given diameter and d is the diameter of the particle cubed. Both volume and mass are used interchangeably since a particle density of 1.0 is assumed. The total volume value may be thought of in terms of micrograms, and the percentages listed at specific size intervals allow one to calculate how many micrograms of material can be found at a specific size range.

The elemental composition of the dust particles was subcontracted to another laboratory (R.J. Lee Group, Inc., Materials and Environmental Services, Monroeville, PA) that performed an energy dispersive spectroscopy (EDS) technique, which is a chemical microanalysis technique performed in conjunction with a scanning electron microscope (SEM). This technique utilizes x-rays that are emitted from the sample during bombardment by an electron beam. The EDS x-ray detector measures the number of emitted x-rays versus their energy. The energy of the x-ray is characteristic of the element from which the x-ray was emitted. Lateral resolution of about 1 μm is possible. The elemental composition is illustrated as spectral peaks on the SEM graphic scan plot of a specific dust particle.

Laser Strategic Aerosol Monitor (SAM) (Two)

"The laser aerosol monitor (SAM, Model 2005, PPM, Inc., Knoxville, TN.), is a real-time, microprocessor based, electro-optical instrument providing mass concentration measures of particulate concentrations (expressed in $\mu g/m^3$) and optionally, particle sizing distributions that are expressed in nine channels by size (1.25, 3.00, 4.25, 6.00, 8.50, 12, 17, 24, and >24 μm in diameter). The small particle component of sampled air is electro-optically weighed as mass concentration, and the large particle component is sized according to the projected area, and then converted to mass via an algorithm." The SAM flow rate was maintained at 1.5 L/min. It was calibrated for agriculture dust at the factory, and it utilized a proprietary automatic calibration and zero methods. The SAMs collected dust every 3 minutes, and the total dust was calculated every hour for 24 h, and data were collected for 8 d.

Cyclone Air Sampler

Two cyclone air samplers (In-Tox Products, Albuquerque, NM) were made of brass piping with slip joints and specifically designed chambers that collected particulates based on their aerodynamic diameters (5.2 μm to 1 μm) into five chambers and finally the smallest particles (0.32 μm in diameter) were collected onto a filter. Vacuum pumps (Model 1531-320-G557X, Gast Mfg., Benton Harbor, MI) attached to the cyclone devices were calibrated to maintain a flow rate of 28.4 L/minute for 24 h. The cyclone intake orifice height was placed at 1 m. After collection of dust particles, the device was disassembled and the particulates weighed on an analytical balance.

Biological Cascade Impactors

Two-stage and 6-stage impactors (Andersen Instruments, Atlanta, GA) were used previously to determine the concentration of bacteria, fungi, and endotoxin in the air of Southern High Plains feedyards (Purdy et al. 2004). Vacuum pumps were calibrated to operate at a flow rate of 28.3 L/min. This time, the cascade impactors were used in the four feedyards to determine the size of the viable respirable (<5 μm in diameter) and non-respirable colony forming unit (CFU) (>5 to 10 μm in diameter) based on the stage of the device they impacted. Stage-0 of the 2-stage impactor and stages 1, 2, and 3 of the 6-stage impactor were considered non-respirable and stage-00 of the 2-stage impactor and stages-4, 5, and 6 of the 6-stage impactor were considered respirable. We collected mesophilic aerobic bacteria for 5 min, *Enterococcus spp* for 15 min, and fungal particles for 15 min in the feedyards. The viable CFUs are reported as CFU /m^3 of air. Sampling time had no effect on microorganism recovery as no viable Gram negative bacteria were recovered on shorter collection times.

Weather Station

Weather conditions were monitored for each feedyard by use of a portable weather station (Model Met Data1, Campbell Scientific, Logan, UT) equipped with a 3.5 m tower. The weather station measured wind speed, wind direction, relative humidity, precipitation, air temperature, solar radiation, barometric pressure, and time. The sampling time occurred at 30 sec intervals and the recording times were at 15 min, 1 h, and 24 h intervals.

Statistical Analysis

The experiment was conducted as a completely randomized design with air sample as the experimental unit. Data were analyzed with an ANOVA by use of a general linear models procedure (SAS 1988). The model included a 2-way ANOVA with interactions that examined the effect of season and feedyard on the microbial populations, and on the respirable 2.5 μm in diameter and non-respirable 10 μm in diameter size particulate populations. Significant differences between groups were further evaluated by use of the Bonferroni adjusted paired t-test. Differences were considered significant at $P \leq 0.05$. Proc Correlation procedure was used to analyze correlations between RAAS PM_{10} and $PM_{2.5}$ ambient air collection (μg/m^3) and the weather components (relative humidity %, wind speed m/s, wind direction, solar radiation [W/m^2], and barometric pressure [mm Hg]). The Proc Correlation analysis was reported as Pearson Correlation Coefficients. The significance of Pearson correlations were evaluated using the two-tailed F-statistics which provides the test of the null hypothesis that r (or R^2) is zero (Pr < f).

RESULTS

Comparison of FRM sequential PM_{10} and PM $_{2.5}$ Particulate Data $\pm$ Standard Error of the Means (SEM)

Downwind PM_{10} mean particulates, 268.86 $\pm$ 32.39 μg/m^3, and upwind PM_{10} mean particulates, 93.65 $\pm$ 16.88 μg/m^3, of four feedyards were significantly different ($P \leq 0.0001$) for the overall model statement. Due to faulty $PM_{2.5}$ monitors in FY 3 which collected larger particles than expected, these data were removed from the statistics. Similarly downwind $PM_{2.5}$ mean particulates, 25.27 $\pm$3.00 μg/m^3, and $PM_{2.5}$ upwind mean particulates, 13.96 $\pm$1.66 μg/m^3, were significantly different for the overall model statement ($P \leq 0.001$).

Summer PM_{10} mean particulates, 261.78 $\pm$ 34.28 μg/m^3, and winter PM_{10} mean particulates, 97.70 $\pm$ 12.88 μg/m^3, of these feedyards were significantly different for the overall model statement. $PM_{2.5}$ summer mean particulates, 26.40 $\pm$ 3.12 μg/m^3, and winter mean particulates, 12.83 $\pm$ 1.13 μg/m^3, of these feedyards were also significantly different for the overall model statement.

Three feedyards (FY1, FY2, and FY3) had significantly ($P \leq 0.05$) more PM_{10} mean total dust particulates than FY5. Two feedyards (FY1 and FY2) had significantly ($P \leq 0.05$) more $PM_{2.5}$ mean total dust particulates than FY5. The mean particulate data for each feedyard during the winter, summer, downwind and upwind are presented (Table 1). The specific feedyard contribution of particulate dust was determined from the RAAS 300 PM_{10} and $PM_{2.5}$ data by calculating the difference between upwind and downwind concentration (Table 1): PM_{10}; FY1, 272.24 μg/m^3, FY2, 274.84 μg/m^3, FY3, 130.96 μg/m^3, FY5, 29.63 μg/m^3; $PM_{2.5}$; FY1, 12.18 μg/m^3, FY2, 18.18 μg/m^3, FY3,–3.86 μg/m^3, and FY5, 3.58 μg/m^3 of air.

TABLE 1
PM_{10} & $PM_{2.5}$ mean particulate filter data[a] of 4 feedyards (FY)

	N	Site P value	Downwind N	Downwind Mean ($\mu g/m^3$)	Downwind SEM	Upwind N	Upwind Mean ($\mu g/m^3$)	Upwind SEM
PM_{10}								
FY1	32	0.001	15	362.19	59.83	17	89.95	19.93
FY2	32	0.001	16	363.19	85.11	16	88.35	37.97
FY3	32	0.05	16	275.01	54.69	16	144.05	51.85
FY5	32	0.07	16	80.90	14.39	16	51.27	8.06
$PM_{2.5}$								
FY1	32	0.001	16	30.13	3.36	16	17.95	1.70
FY2	32	0.002	16	33.51	7.28	16	15.33	4.38
FY3[b]	32	0.65	16	24.58	4.44	16	28.44	8.47
FY5	32	0.05	16	12.18	1.20	16	8.60	0.93
	N	Season P value	Summer N	Summer Mean($\mu g/m^3$)	Summer SEM	Winter N	Winter Mean ($\mu g/m^3$)	Winter SEM
PM_{10}								
FY1	32	0.001	16	349.19	57.69	16	85.94	20.12
FY2	32	0.001	16	405.08	83.03	16	46.46	4.81
FY3	32	0.83	16	216.44	70.59	16	202.62	35.53
FY5	32	0.20	16	76.39	15.08	16	55.78	7.72
$PM_{2.5}$								
FY1	32	0.003	16	28.25	7.09	16	19.83	2.17
FY2	32	0.001	16	39.82	7.09	16	9.02	1.12
FY3[b]	32	0.27	16	31.49	9.04	16	21.53	2.61
FY5	32	0.35	16	11.13	1.27	16	9.65	1.02

[a]RAAS 300 Series monitors collected particles over 8 days in winter and summer at upwind and downwind positions (mean [$\mu g/m^3$ of air] ± standard error of mean [SEM]).
[b]The FY3 $PM_{2.5}$ data were removed from the statistics due to the malfunction of the monitor; however, the data were left in the table.

There were very few correlations between specific weather variables and dust collected in the feedyards using the RAAS 300 collectors. When the summer and winter data were combined, there was a significant ($P < 0.002$) coefficient of correlation between the air temperature (0.52) and the dust collected by PM_{10} instruments, and between air temperature (0.42) and dust collected by $PM_{2.5}$ instruments. There were no high correlations between RAAS 300 collectors and weather variables in upwind data sets. However, in the downwind data sets there were significant ($P < 0.0001$) coefficient of correlations between PM_{10} and air temperature (0.72), maximum relative humidity (–0.55), and solar radiation (0.48), and between $PM_{2.5}$ and air temperature (0.63) and solar radiation (0.47). There were significant ($P < 0.004$) coefficients of correlations between summer data sets for PM_{10} and air temperature (0.48), maximum relative humidity (0.41), and for $PM_{2.5}$, and air temperature (0.42). No high coefficient of correlations was seen in the winter data sets.

Independent Laboratory Analysis

The RAAS 300 PM_{10} and $PM_{2.5}$ collection filters from FY1, FY2, and FY3 upwind and downwind were analyzed by the Elzone (Coulter Counter) method. The mass (Figure 1) and the population particulate count (Figure 2), and geometric mean size of particles are shown. The dust from FY1, FY2, and FY3 is shown as $\mu g/m^3$ of air by the mean particle size distribution percentiles for $PM_{2.5}$ (Figure 3, Part A) and PM_{10} (Figure 3, Part B).

The PM_{10} upwind and downwind data are shown as percent of total particles (Figure 4) and similar data are presented for $PM_{2.5}$ upwind and downwind (Figure 5). Data are shown for FY1 and FY3 (Figure 5). The amount of dust collected from FY2 $PM_{2.5}$ filters for days 1, 2, and 3 were combined for both upwind and downwind samples which were considered inadequate for the Elzone analytical method. Therefore, these filters were subcontracted to another laboratory for analysis with a scanning electron microscope (SEM) using energy dispersive spectroscopy (EDS). Pieces of PM_{10} filters (days 1–3) from FY1 downwind were also submitted to the subcontractor for analysis. The electronic images of the dust particles (from $PM_{2.5}$ and PM_{10} filters) gave us further confirmation of the dust population distribution and range of particle sizes in equal distant percentiles (Table 2). It also showed the shape of dust particles emitted from the feedyard and analyzed their elemental composition (Figure 6).

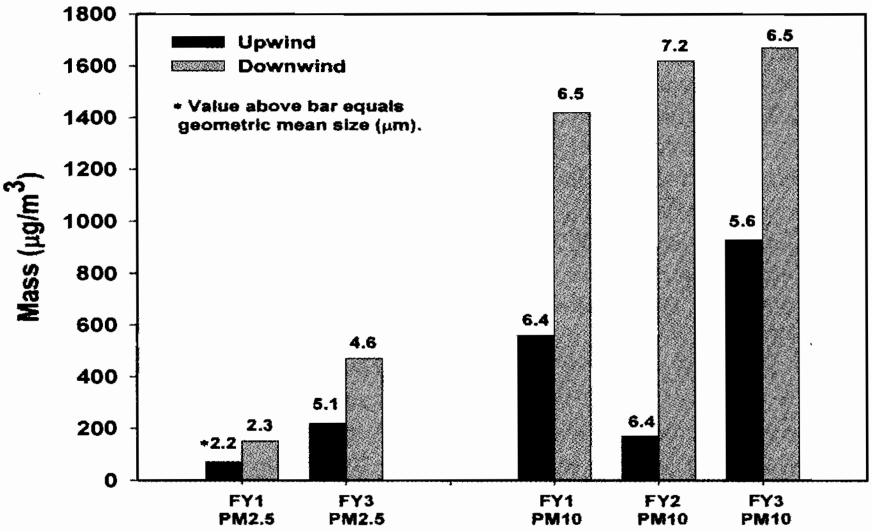

FIG. 1. PM_{10} and $PM_{2.5}$ dust composite over days 1, 2, and 3 were analyzed by the Elzone method for mass and the geometric mean size are presented for FY1, FY2, and FY3 at the upwind and downwind positions. *Note*: The Elzone information for $PM_{2.5}$ from FY2 is missing due to insufficient amount of dust collected on the filters.

Most of the EM analyzed particles clearly appear to be from soil derived clays, as they were rich in aluminum and silicon; however, some particles were composed only of calcium carbonate and they were probably from caliche soil or road dust. One EM analyzed particle had a crystal mingled in with other material which may have come from dried urine.

Laser Strategic Aerosol Monitor (SAM)

The laser strategic aerosol monitors produced data every 3 minutes, but these data were consolidated into hourly units for better management and for a better fit with the hourly weather data. The overall statistical model statement showed a significant difference ($P \leq 0.0001$) between dust concentration downwind, 339 ± 26 $\mu g/m^3$, and upwind, 143 ± 10 $\mu g/m^3$. The overall hourly mean feedyard dust concentration clearly indicated that the highest concentration of dust occurred between the hours of 1800 and 2300 (Figure 7). Feedyard dust concentration was calculated for various particle sizes (1.25 μm through >24 μm in diameter) within each feedyard and among feedyards (two-way interaction) (Figure 8).

There was a significant ($P \leq 0.0001$) difference in the over all model statement for SAM mean concentration of dust data for season ($P \leq 0.0001$), summer, 428 ± 47 $\mu g/m^3$, and winter,

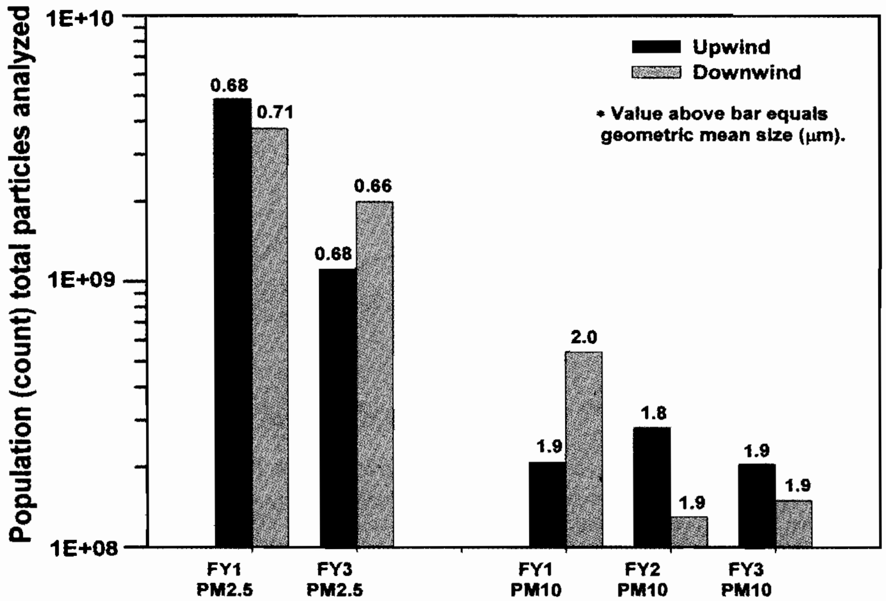

FIG. 2. PM_{10} and $PM_{2.5}$ dust composite over days 1, 2, and 3 were analyzed by the Elzone method for population (count) and the geometric mean size are presented for FY1, FY2, and FY3 at the upwind and downwind positions. *Note*: see FIG. 1.

234 ± 25 $\mu g/m^3$, feedyards ($P \leq 0.001$), FY1, 192 ± 25 $\mu g/m^3$, FY2 460 ± 53 $\mu g/m^3$, FY3, 341 ± 48 $\mu g/m^3$, and FY5, 372 ± 97 $\mu g/m^3$. There was a Pearson correlation coefficient of 0.59 between air temperature ($P \leq 0.001$) and time (1800 h) and 0.52 between windspeed (m/s) ($P \leq 0.001$ through 2100 h and at 2300 h) and time (1800 h). There was a significant three way interaction for SAM mean concentration data among feedyards ($P \leq 0.03$) at two time periods during the day at 1400 h and 1700 h in the summer. However, there were many more significant three way interactions in the winter; e.g., 100 h through 800 h, 1600 h through 1800 h, and 2000 h.

Cyclones

The overall model statement for the collection of dust by the cyclones was significant ($P \leq 0.0012$). There was significantly more dust collected in the 1st stage than in the other 4 stages and on the filter. There was a significant ($P \leq 0.04$) difference between ambient air upwind, 22.24 ± 4.58 $\mu g/m^3$, and downwind, 109.71 ± 53.98 $\mu g/m^3$ samples, and almost a significant ($P \leq 0.06$) difference between winter, 26.05 ± 6.68 $\mu g/m^3$, and summer, 105.89 ± 53.89 $\mu g/m^3$ samples. There were no significant differences in ambient air samples between feedyards.

Biological Cascade Impactors

The size of the CFU impacting each stage containing media was analyzed statistically for the overall model statement (data presented as mean CFU/m^3 of air). The CFU particle size data sets for aerobic bacteria, *Enterococcus spp*, and fungal CFU

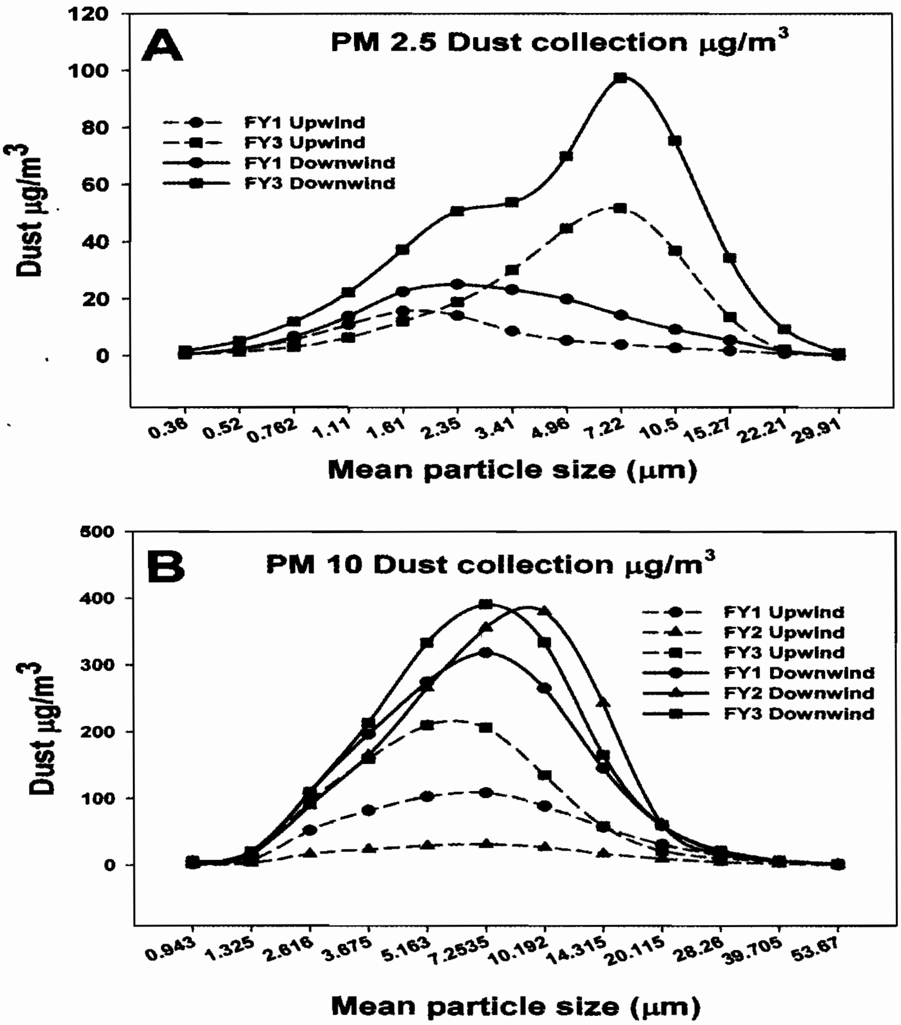

FIG. 3. Part A, is the Elzone (Coulter method) analysis of the feedyard particulates collected on filters by RAAS 300 $PM_{2.5}$ monitors in the summer, upwind and downwind of feedyard 1 and feedyard 3. Twenty-four hour filters for day 1, 2, and 3 were pooled in order to have adequate dust for the analysis. Data are presented in equal distant percentiles by quantity in $\mu g/m^3$ ofair and mean size (μm in diameter). Part B, is the Elzone (Coulter method) analysis of the feedyard particulate collected on filters by RAAS 300 PM_{10} monitors in the summer, upwind and downwind of feedyards 1, 2and 3. Filters for day 1, 2, and 3 (are matched on the same days as Part A) were pooled in order to have adequate dust for the analysis. Data are presented in equal distant percentiles by quantity in $\mu g/m^3$ of air and mean size (pm in diameter).

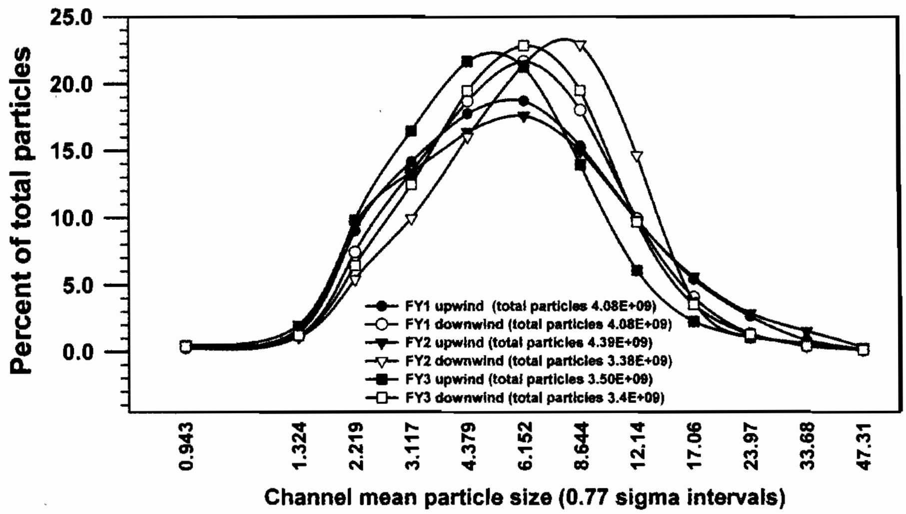

FIG. 4. Feedyard PM_{10} Elzone analysis of parti culates on filters (day 1, 2, and 3 combined), percent of total particles and mean particle size by channel (0.77 sigma intervals) from upwind and downwind of three feedyards (FY1, FY2, and FY3).

were combined and analyzed by individual stages ($P \leq 0.0001$) for both the 2-stage and 6-stage cascade impactors. The mean non-respiratory CFU (stage 0) of the 2-stage impactors had significantly more CFU/m^3 (695 ± 109^a) than (stage 00) respirable (471 ± 56^b) CFU/m^3. The superscripted under case letters indicate Bonferroni adjusted paired t-test analysis, significant at the $P < 0.05$. The mean numbers of CFU's for each stage of the 6-stage impactor were: stage 1, 339 ± 66^{bc}CFU/m^3, stage 2, 342 ± 74^{bc}CFU/m^3, stage 3, 383 ± 76^{bc} CFU/m^3, stage 4, 438 ± 73^b CFU/m^3, stage 5, 283 ± 45^{cd}CFU/m^3, and stage 6,161 ± 33^d CFU/m^3 (data not shown in Table 3). There were significantly more CFU particles impacting stage 4 (437 ± 73 CFU/m^3) compared to the other stages, and the fewest CFU particles impacted stage 6 (161 ± 33 CFU/m^3). There were significantly ($P \leq 0.0001$) more CFU particles downwind, 578 ± 46 CFU/m^3, than upwind, 200 ± 17 CFU/m^3, more in summer, 561 ± 47 CFU/m^3, than in winter, 217 ± 16 CFU/m^3, and more in FY1, 528 ± 68 CFU/m^3, compared to the other 3 feedyards (FY2, 365 ± 44 CFU/m^3, FY3, 377 ± 47 CFU/m^3, and FY5, 286 ± 34 CFU/m^3). There were no significant differences in CFU particle numbers collected in the AM, 406 ± 38 CFU/m^3, and PM, 372 ± 32 CFU/m^3, from the combined data sets. The 2-stage impactor was significantly ($P \leq 0.0001$) different in mean non-respirable particles, 694 ± 109 CFU/m^3, and mean respirable particles, 471 ± 56 CFU/m^3, compared to the 6-stage impactor ($P \leq 0.08$) mean non-respirable particles, 1064 ± 211 CFU/m^3, and mean respirable particles, 881 ± 135 CFU/m^3. There were significant ($P \leq 0.0001$) differences

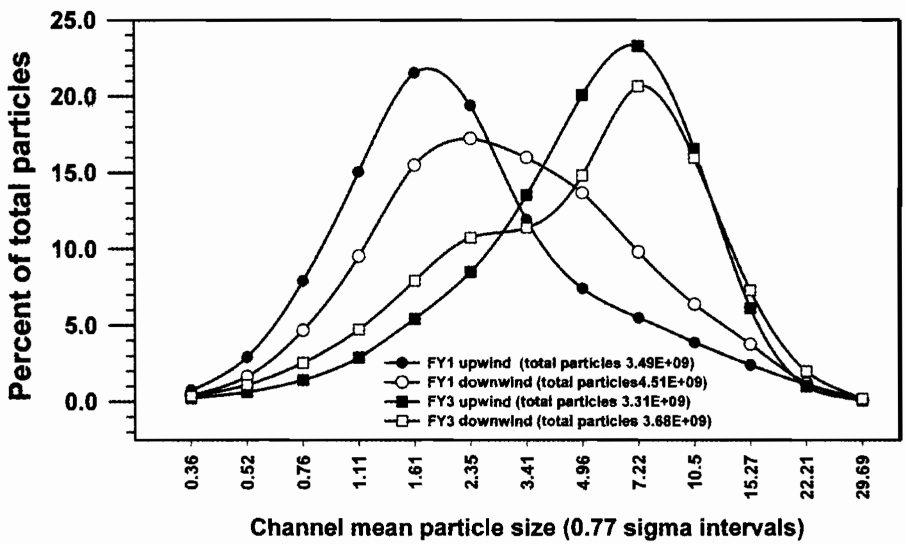

FIG. 5. Feedyard $PM_{2.5}$ Elzone analysis of particulate on filters (days 1, 2, and 3 combined), mean (standard deviation [SD]) of total particles, and size data by percentiles (0,77 sigma intervals) from upwind and downwind of two feedyards.

in the number of non-respirable and respirable particles (for 2-stage and 6-stage impactors) in the summer and winter, downwind and upwind, and in the AM and PM (data not shown in Table 3).

Viable respirable and non-respirable mean sized CFUs were analyzed using the cascade 2-stage and 6-stage impactor data for mesophilic aerobic bacteria, *Enterococcus spp* , and fungal CFU/m^3 of air. The overall model statement was significant ($P \leq 0.0001$) for CFU particle size ($P \leq 0.015$), seasons ($P \leq 0.0001$), downwind and upwind site ($P \leq 0.0001$), time (AM and PM) ($P \leq 0.002$), and feedyards ($P \leq 0.0001$), but no significant difference occurred between 2-stage and 6-stage impactor mean CFU collections.

There were overall, significantly more mean non-respirable aerobic bacteria, 2456 ± 312 CFU/m^3, and *Enterococcus spp,* 94 ± 40 CFU/m^3, compared to mean respirable aerobic bacteria, 1856 ± 179 CFU/m^3, and, *Enterococcus spp*, 27 ± 10 CFU/m^3, and there were significantly more mean respirable fungi, 146 ± 8 CFU/m^3, than mean non-respirable fungi, 90 ± 8 CFU/m^3.

There were significantly ($P \leq 0.0001$) more mean non-respirable aerobic bacteria, 3933 ± 970 CFU/m^3 in FY1 than in FY2, 2063 ± 484 CFU/m^3, FY3, 2303 ± 489 CFU/m^3, and FY5, 1524 ± 272 CFU/m^3, and there were no significant differences in mean respirable aerobic bacteria (range, 1624 ± 317 CFU/m^{3}to 2036 ± 362 CFU/m^3) among the four feedyards. It is interesting that the number of bacteria were not significantly different in any of the six stages for aerobic bacteria collected upwind (range, 300 CFU/m^{3}to 480 CFU/m^3), PM (range, 585 CFU/m^{3}to 1110 CFU/m^3), FY2 (range, 546 CFU/m^{3}to 1061 CFU/m^3), and FY5 (range, 571 CFU/m^{3}to 733 CFU/m^3), however, the number of particles were significantly different for most of the six stages for mesophilic fungi collected upwind (range, 15 CFU/m^{3}to 92 CFU/m^3), PM (range, 10 CFU/m^{3}to 76 CFU/m^3), and 4 feedyards (range, 12 CFU/m^3 to 121 CFU/m^3).

The mean number of non-respirable and respirable CFUs were significantly ($P \leq 0.0005$) different for *Enterococcus spp* and fungal CFUs among the feedyards. There were significantly more *Enterococcus spp* mean non-respirable bacteria in FY2, 300 ±155 CFU/m^3 than in FY1, 16 ±6 CFU/m^3, FY3, 3 ±1 CFU/m^3, and FY5, 57 ±19 CFU/m^3; also, there were significantly more *Enterococcus spp* mean respirable CFUs in FY2, 78 ± 37 CFU/m^{3}than in FY1, 5 ± 2 CFU/m^3, FY3, 2 ± 1 CFU/m^3, and FY5, 23 ± 6 CFU/m^3.

The mean non-respirable and respirable fungi were significantly ($P \leq 0.0001$) different among feedyards: non-respirable fungi were significantly ($P \leq 0.05$) higher in FY1, 187 ± 24 CFU/m^3, than in FY2, 60 ± 7 CFU/m^3 , FY3, 36 ± 5 CFU/m^3 , and FY5, 75 ± 10 CFU/m^3. There were significantly ($P \leq 0.05$) more mean respirable fungi in FY2, 170 ± 24 CFU/m^3, than in FY1, 139 ± 14 CFU/m^3, FY3, 141 ± 21 CFU/m^3, and FY5, 133 ± 14 CFU/m^3.

Non-respirable and respirable microbial CFU/m^3 were compared by using three data sets (aerobic bacteria, *Enterococcus spp*, and fungi) collected by 2-stage and 6-stage cascade impactors, during the summer and winter, downwind and upwind, AM and PM, and among the four feedyards (Table 3).

Weather Station

Weather conditions during the sampling periods were: wind direction in the summer was predominantly out of the southwest, and in the winter it was predominantly out of the northwest. Mean wind speed in summer was 10.3 ± 0.73 m/s, and ranged from a maximum of 29.8 to a minimum of 5.3 m/s, and in the winter was 10.15 ± 0.45 m/s and ranged from a maximum of 15.4 to a minimum of 5.7 m/s. The mean air temperature in the summer was 23.1 C ± 0.74, and in the winter was 7.8 C ± 0.88. The percent relative humidity in the summer ranged from a maximum of 95% to a minimum of 11.2% and in the winter ranged from a maximum of 98% to a minimum of 6.3%. The mean daily total solar radiation was 267.13 ± 11.29 W/m^2 in the summer and 199.65 ± 11.29 W/m^2 in the winter. The mean rain fall in the summer for all sampling days was 1.66 ± 0.96 mm and in the winter was 0.46 ± 0.29 mm. The mean barometric

TABLE 2
Scanning electron microscopy analysis of feedyards (FY) dust

Sample ID	Position	#Particles	0.35	0.75	1.75	3.75	7.50	15.00	>20
		Number percent distribution by average diameter (μm)							
$FY2PM_{2.5}$	Upwind	6946	23.72	33.86	40.43	1.82	0.17	0.00	0.00
$FY2PM_{2.5}$	Downwind	4468	18.73	28.30	39.54	10.59	2.61	0.22	0.00
$FY1PM_{10}$	Downwind	7767	17.09	18.23	30.34	22.64	10.74	0.96	0.00
		Volume percent distribution by average diameter (μm)							
$FY2PM_{2.5}$	Upwind	6946	0.24	5.08	50.16	19.43	25.09	0.00	0.00
$FY2PM_{2.5}$	Downwind	4468	0.04	0.68	10.05	25.39	38.16	25.68	0.00
$FY1PM_{10}$	Downwind	7767	0.01	0.14	2.96	18.85	53.83	24.22	0.00

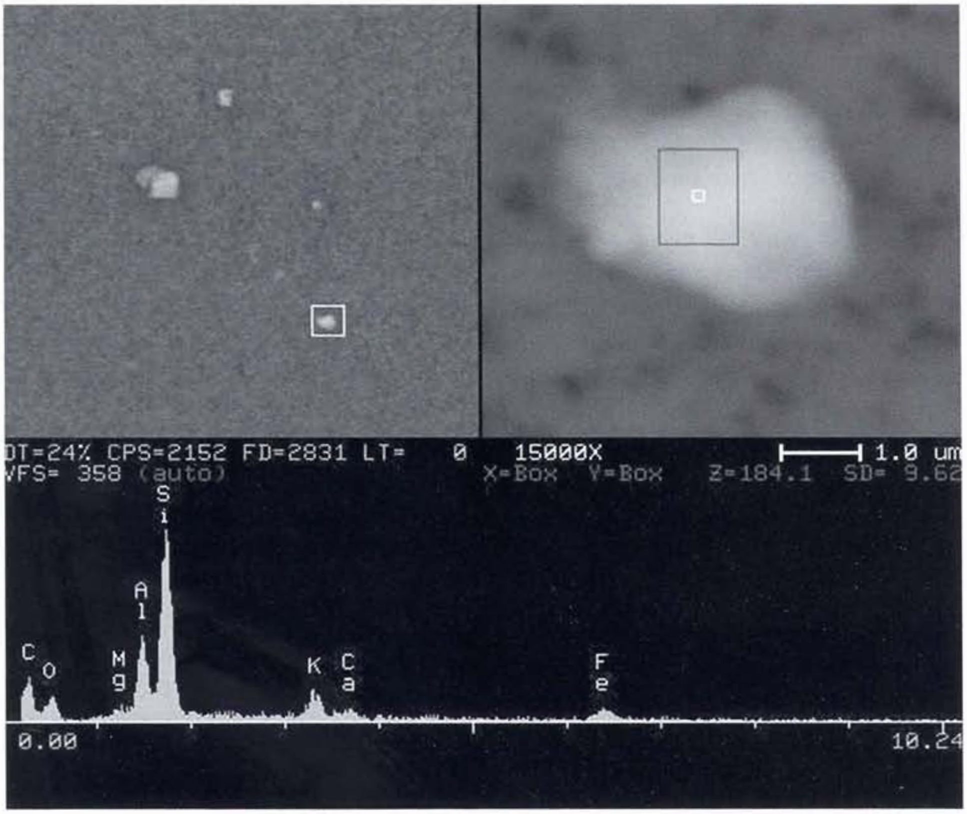

FIG. 6. Scanning electron microscope graphic scan plot of a downwind $PM_{2.5}$ is filter from FY2. The particle is rich in Si and Al and appears to be a clay particle; note the amorphous shape.

pressure in the summer was 663.6 ± 0.52 mm of Hg and in the winter was 661.6 ± 0.82 mm of Hg.

DISCUSSION

The present study provides much needed information concerning non-respirable and respirable particulates pertaining to the atmospheric concentrations of feedyards in the Southern High Plains of Texas in the winter and summer. Diverse types of aerosol equipment were used to determine if similar data could be generated by various types of equipment, and to determine which types of equipment were the most practical to use under actual feedyard conditions in the Southern High Plains. We started with EPA-accepted high-volume reference ambient air samplers (RAAS $PM_{2.5}$ and PM_{10}), which collected aerosols gravimetrically over an 8-day period. Agencies responsible for public health have in the last few years placed much emphasis on particle size and composition as well as the quantity of particulates in the air. The proposed EPA $PM_{2.5}$ threshold limit (average annual limit of 15 $\mu g/m^3$and a 24 h standard of 65 $\mu g/m^3$) has become very political and controversial concerning cost and benefits. The EPA's new proposed $PM_{2.5}$ standard will be based on a temporal (3-year) and spatial averaging of concentrations (Blodgett et al. 1997). The American Public Health Association (APHA) supports the EPA decision to use a three-year arithmetic mean but has reservations over the use of spatial averaging to determine the mean concentration for an area. The APHA suggested that EPA lower the 24 h $PM_{2.5}$ standard to (<20 $\mu g/m^3$) (Comments Amer. Pub. Health Assoc. 1997).

The RAAS PM_{10} data reflected what was expected of the PM_{10} monitors (Table 1) and the results (size particle and quantity of dust) were confirmed by an independent company that analyzed a sample of the same filters collected by the PM_{10} monitor (Figure 3). The mean (7.25 μm size particle) and single mode for the quantity of downwind dust (300 to 400 $\mu g/m^3$ dust in air) were bell shaped curves after transformation, and the upwind particles were of similar size and showed approximately 10 to 200 $\mu g/m^3$ of dust concentration in the air. The dust data collected for the $PM_{2.5}$ at FY3 downwind demonstrated a bimodal curve. The first mode was at 2.35 μm size particles where it was designed to collect, and a second mode was between 7 and 10 $\mu m/m^3$ size particles where it was not expected to collect, and the quantity of dust was between 10 to 100 $\mu g/m^3$. The FY3 $PM_{2.5}$ upwind data also indicated that it was collecting larger particles than expected (>7.22 μm in diameter in size). Thus, under feedyard conditions the $PM_{2.5}$ monitors appeared to collect larger size particles than was expected. This may be due to not changing the WINS filter often enough (every 8 days) under such dusty conditions. It appears that if this filter becomes overloaded, particle bounce occurs and larger particles are collected by this instrument. In the future, we will change this filter each day of operation to see if that will stop the collection of larger particles. We also tried to prevent dust infiltration of the cabinets by duct taping over the door seams prior to leaving the feedyards.

Using the Elzone technique, geometric mean sizes of the PM_{10} upwind particles were from 0.782 to 1.944 μm in diameter and that of $PM_{2.5}$ upwind particles were from 0.675 to 0.680 μm in diameter. And, the geometric means for PM_{10} downwind particles were from 1.889 to 2.016 μm in diameter and $PM_{2.5}$ downwind particles were from 0.655 to 0.714 μm in diameter. These results explain why feedyard fine dust particles often stay suspended in the air for many hours and frequently drift for some distance downwind.

Soil scientists reported (Lyles 1988) that eroding soil (3 to 38 percent) was carried in suspension, the amount was dependent on the soil texture, and that the vertical transport was usually <10% of the horizontal (Cullen et al. 2000). The highest dust frequency occurs, when the visibility is less than 11 km, and this occurs regularly in the Southern Great Plains, where most of the area is affected by dust one percent of the time and a small part of this area is affected by dust 3% of the time. The highest density of soil-derived dust in the Southern Great Plains happens in the afternoon between 1200 and 2000 h local standard time (Orgill and Sehmel 1976). Fine particles of dust (1 to 10 μm in diameter) are richly supplied by the presence of organic material (manure in the feedyard) in the soil (Chepil 1945). There is a remarkable similarity in aerosol concentration from the feedyards to what has been known for 60 years about soil erosion in the Southern Great Plains.

The actual concentration of dust generated from the feedyards, calculated from the PM_{10} (Table 1) data by subtracting the mean upwind (background dust) from the mean downwind dust, indicates that FY1 had 272 $\mu g/m^3$ and FY2, 275 $\mu g/m^3$ dust calculated over 16 days (8 days in the summer and 8 days in the winter). This exceeded the mean 24 h amount of dust permitted by the EPA for a primary concentration standard of 150 $\mu g/m^3$ (primary National Ambient Air Quality Standards [NAAQS])[14] and FY3 (131 $\mu g/m^3$) exceeded the secondary 24 h standard of 130 $\mu g/m^3$, but FY5 at 30 $\mu g/m^3$ easily met the mean 24 h PM_{10} primary and secondary standard requirement. It appears that all four feedyards (Table 1) would fall below the proposed $PM_{2.5}$ concentration standard for 24 h. However, as of September 21, 2006 this standard was lowered by EPA to 35 $\mu g/m^3$, thus FY2 in the summer (39.8 $\mu g/m^3$) would not be in compliance for $PM_{2.5}$ particulates. If one considers that the 16 days chosen to study aerosols in the feedyards were not unique to any 16 days in the year, there could be potential non-compliance for some feedyards to meet the PM_{10} NAAQS annual standard regulation, which is not to exceed a mean 50 $\mu g/m^3$/y.

The Elzone feedyard PM_{10} percent of total particles were compared upwind and downwind for three FYs by mean size of particles (9 different channels) (Figure 4). FY1, FY2 and FY3 showed more mass concentration of dust downwind than upwind. The mean size of particles downwind was: FY1, 8.25 μm, FY2, 8.59 μm, and FY3, 7.90 μm in diameter and the mean size of the dust particles upwind was: FY1, 8.25 μm, FY2, 8.53, and FY3, 6.90 μm in diameter (data not shown in Figure 4). However, there was more diversity with the Elzone feedyard $PM_{2.5}$ percent of total dust particles (Figure 5) by mean size of particles (9 different channels) for FY1 and FY3. The upwind for FY1 showed the highest mass concentration of dust, 21.53% with a mean of 1.61 μm in diameter particle size, while FY3 had the highest mass concentration of dust, 23.29% with a mean of 7.22 μm in diameter particle size, and FY1 downwind mass concentration of dust, 17.24% with a mean of 2.35 μm in diameter particle size, and FY3 downwind mass concentration of dust, 20.66% with a mean of 7.22 μm in diameter particle size. These data clearly show that the $PM_{2.5}$ monitor is collecting appropriate size particles both upwind and downwind for FY1, but not for FY3. In FY3 the downwind first bimodal peak is seen at a mean of 2.35 μm to 3.41 μm size in diameter particles, and the second modal peak occurs at a mean of 7.22 to 10.50 μm size in diameter particle. We did not generate any statistics from the Elzone data. Data were compared only vertically for the same channel size of particles. Geometric mean sizes were supplied by the subcontractor.

The scanning electron microscopic analysis of upwind and downwind (Table 2) dust from FY2 indicated that the volume (mass) percentiles by mean size of particle produced similar data to that of the Elzone method (Figure 5) for FY1. For example, the SEM analysis for FY2 upwind (Table 2) dust gave the largest volume (mass), 50.16 percentile with a mean of 1.75 μm size diameter particle, which is what the cutoff for a $PM_{2.5}$ should be. However, the FY1 $PM_{2.5}$ downwind (Figure 5) showed the largest volume (mass) 19.40 percentile with a mean particle size (2.35 μm in diameter). The SEM scan of the FY1 PM_{10} downwind (Table 2) produced the largest volume (mass), 53.83 percentile with a mean particle size of 7.50 μm in diameter which is what the PM_{10} monitor should be collecting, and can be seen graphically by the Elzone method for FY1 downwind (Figure 4).

In addition, the SEM scans of 25 individual particles indicated that the particles were all amorphous in shape. The elemental structure for each particle was profiled. One example is given (Figure 6). Most particles examined were rich in aluminum and silicon which indicates that most particles examined were from mineral soil clay particles. Probably a large percentage of these particles came from road dust stirred up by rapidly moving vehicles.

The SAM data showed the highest concentration of dust occurred in all 4 feedyards between the hours of 1800 through 2300 with a sharp decline following 2300 h (Figure 7). The mean dust concentrations of 4 feedyards for nine channels of the SAM data are shown (Figure 8). The largest amount of animal activity occurs because of cattle behavior in the evening

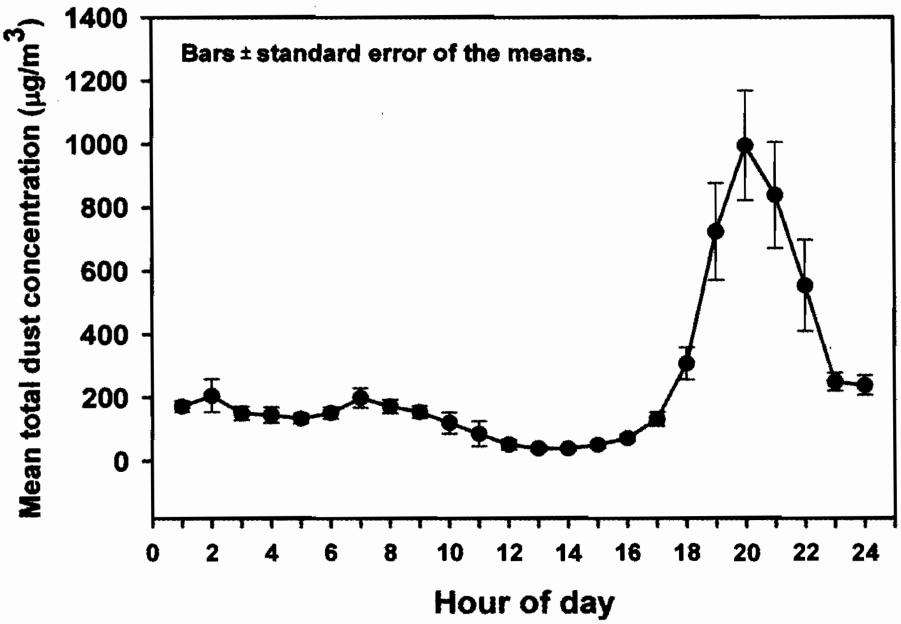

FIG. 7. Laser strategic aerosol monitor (SAM) data from four feedyards depicts channel mean total dust concentration ng/m^3 ± standard error of mean (SEM) of air (9 channels) for each hour of the day which indicates a sharp rise in dust concentration at 1800 h, maximum at 2100 h, and a sharp decline at 2200 h.

hours and this activity generates the highest concentration of dust which has been previously reported (Sweeten et al. 1988; Wilson et al. 2002; Gonyou and Stricklin 1984). The difference dust concentration of particle sizes (Figure 8) among feedyards probably indicates a different soil types (Miller and Woodbury 2003). The SAM dust concentration data (downwind minus upwind) for the feedyards was: FY1, 191.57 ± 25.41 μg/m^3, FY2, 459.54 ± 53.39 μg/m^3, FY3, 340.66 ± 48.33 μg/m^3, and FY5, 371.94 ± 96.82 μg/m^3. This concentration of dust is larger than that collected by the RAAS PM_{10} monitors for the 4 feedyards, except for FY1 which is 80.69 μg/m^3 less than the RAAS value of 272.24 μg/m^3. The differences in mass concentration of dust collected by these instruments are probably due to the larger size range of particles collected by the SAM instruments.

The cyclone instruments collected significantly more dust in the first chamber than in the other chambers and on the filter, as each chamber collects progressively smaller particles. It collected significantly more dust downwind than upwind, more dust in the summer than winter, and there were no significant differences in the amount (25 μg/m^3 to 126 μg/m^3) of particulates

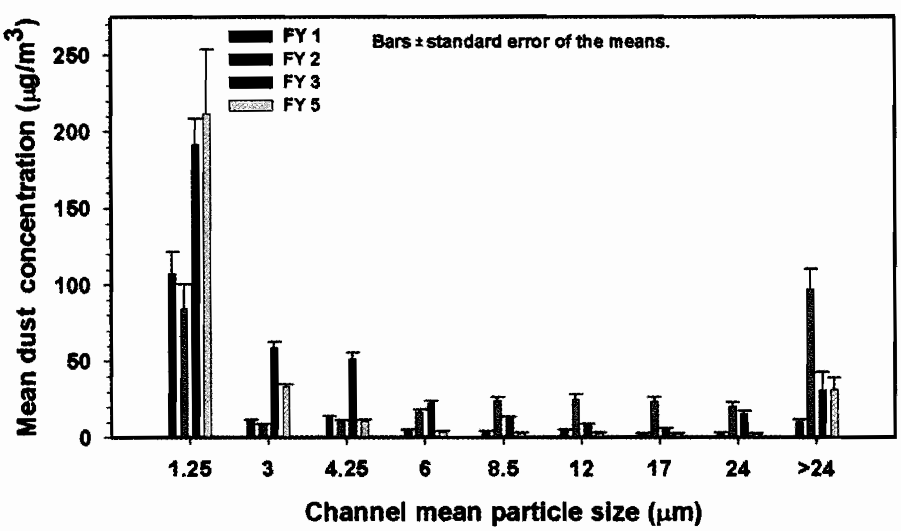

FIG. 8. The general linear model (GLM) two-way interaction for the feedyard mean dust concentration (μg/m^3) and mean particle size (μm in diameter) using laser strategic aerosol monitor (SAM) data.

TABLE 3
Comparison of mean non-respirable combined and respirable combined colony forming units (CFUs) from three data sets[a] (aerobic bacteria, *Enterococcus spp* and fungi)

Parameter	Pr > F value	Number of observations	Particle size Pr > F value	Non-respirable sample number	Non-respirable mean (± SEM)	Respirable sample number	Respirable mean (±SEM)
Summer	0.0001	384	0.0001	192	1370 (± 228)	192	390 (±47)
Winter	0.0001	384	0.001	192	390 (± 47)	192	480 (± 59)
Downwind	0.0001	384	0.0001	192	1383 (± 223)	192	927 (± 132)
Upwind	0.00001	384	0.0001	192	376 (± 66)	192	425 (± 59)
FY1	0.0001	192	0.0001	96	1380 (± 370)	96	732 (±161)
FY2	0.0001	192	0.29	96	808 (± 191)	96	653 (± 145)
FY3	0.0001	192	0.56	96	781 (± 196)	96	726 (± 153)
FY5	0.0001	192	0.37	96	552 (± 114)	96	593 (± 129)
AM	0.0001	384	0.1001	192	980 (± 201)	192	645 (± 99)
PM	0.0001	384	0.42	192	780 (± 128)	192	707 (± 109)

[a]The three data sets were collected by 2-stage (0 and 00) and 6-stage (1–6) cascade impactors, CFUs /m^3 of air ± standard error of mean (SEM). The 2-stage and 6-stage non-respirable CFUs were combined and 2-stage and 6-stage respirable CFUs were combined from the 3 data sets. (*Note*: stages 1, 2, 3, and 0 = non-respirable CFUs and stages 4, 5, 6, and 00 — respirable CPUs.)

collected among the feedyards. Dust particles above 5.2 μg in diameter were excluded by the cyclones and the mass concentration of dust collected appeared to be a little more than that collected by the RAAS $PM_{2.5}$ monitors (Table 1) which are supposed to collect the 2.5 μg mean size particles. The mass concentration of dust was much less than that collected by the RAAS PM_{10} monitors which collected the highest mass concentration of dust in the range of 5 μm particles for upwind and 10 μm particles for downwind which produced bell-shaped curves (Figure 3).

As regards the bioaerosol study, there are a few things gleaned from the data (Table 3). It appears that there are more non-respirable biological particles (in the form of CFUs) in the air around feedyards than there are respirable ones. It is unknown if this phenomenon is due to many microorganisms "sticking together" to form larger particles or if these organisms are on larger inert particles such as dust or soil. We observed significantly more CFUs downwind of feedyards than upwind indicating that the feedyard is a source of bacteria and fungi in the air. It is unknown if these microorganisms are or can be, an important source of infection or induce an allergic response, in man or animals. There were significantly more CFUs in the air of feedyards in the summer as opposed to the winter. This is not surprising as the conditions necessary for bacterial and fungal survival are more favorable in the summer rather than in the harsh environment commonly seen in winter. There did not appear to be any significant difference in the concentrations of CFUs collected in the AM versus those collected in the PM. It is difficult to try to relate the bioaerosols data to the nonviable particulate data because we can't be sure exactly how many living microorganisms are actually on each particle that gives one CFU. For example, *Enterococcus* CFUs may be found on each plate of the 6 stage impactor. Obviously these CFUs are coming from 6 different size of particles, all larger than the size of the microorganism. Also because we don't exactly know what each nonviable particle is composed of, it is difficult to relate their concentration to the bioaerosols data.

Weather station data were valuable in indicating a shift in wind direction and in providing hourly information which fit hourly data collected by the SAM instrument. It also provided correlation data for weather station parameters, SAM and RAAS monitor generated data.

The feedyard environmental dust impact was examined using current aerosol equipment and where possible, standard reference methodology. Next, risk assessment, pertaining to the feedyard dust pollution should be made for animals and humans. If future risk assessment studies determine that feedyard dust is a potential threat to the health of animals and humans, then standard procedures need to be established for the best and most economical way for the feeder calf industry to alleviate the problem of dust pollution. This paper, however, was designed to only establish the existing ambient feedyard particle concentration of 4 large feedyards in the Southern High Plains by using several types of aerosol collection equipment and by using standard reference methods where possible. This study did not address health risk assessment to animal or humans, nor did it address remediation. It is hoped that the results obtained from this work can be used by all concerned. It is our sincere wish that the feeder calf industry have factual information concerning its contribution to dust pollution and its potential impact on the environment. It is also hoped that the regulatory agencies can use the scientific data presented here to help them better design regulations concerning CAFOs based on facts. It is not desirable to economically harm the feeder calf industry, but this industry like the swine industry must take responsibility for any undesirable environmental impact. Hopefully, the feeder calf industry will be pro-active to help alleviate any real negative environmental impact for which they are responsible.

In conclusion, the RAAS PM_{10} and $PM_{2.5}$ mass and size of particle data were very similar to that produced by the Elzone (Coulter Counter) particulate data (population [count] and mass concentration of dust) provided by an independent laboratory. Both the RAAS 300 PM_{10} and $PM_{2.5}$ data were further substantiated by a second independent laboratory which analyzed smaller quantities of dust by a SEM using energy dispersive spectroscopy (EDS) (filters collected by $PM_{2.5}$ and PM_{10} monitors) which provided very similar distribution and size data to that of the Elzone (Coulter Counter) method. In addition, we were provided with the shape and elemental structure of the particles analyzed.

The SAM data provided us with particle distribution by size and mass concentration of particles per meter^3 of air. All three (PM monitors, cascade impactors, and SAM monitors) provided valuable particulate concentration data from four large commercial feedyards in the Southern High Plains in the winter and summer.

The same genera of viable microorganism may be found on each plate of the 6 stage impactor. Obviously these microorganisms are coming from 6 different size of dust particles, all larger than the size of the microorganism.

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